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Economic theory and land prices in land use modeling

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1. Introduction

Long term developments in land use patterns are surrounded by uncertainties. The complexities of land use, exemplified by the fact that land use interacts with most aspects of everyday life, and the incertitude of the future make it difficult to develop founded views and visions on future land use. Several attempts have been made in the past decades to model land use in order to get a better understanding of land use patterns and mechanisms that change land use. Relatively few models have attempted to integrally model all land use categories; the lack of sound integrated theories may be a reason for this.

The past decade showed strong advancements in the development of operational land use models (Wegener, 1994). Geographic information technology, faster computers, and the availability of more and better data made it possible to build comprehensive models. Advances in theoretic development went slower. Theoretic underpinning of models remains in many cases a problem and models rely on statistical analysis to model relations between land use and all kinds of developments.

An integrated land use model that has been developed in the past years is the Land Use Scanner. The Land Use Scanner is a GIS based model for simulating future land use, that has a foundation in economic equilibrium theory. The aim of our study is to compare the economic theory behind the Land Use Scanner with the working of the land market in reality. We will start with an overview of a limited number of economic theories on the land market and subsequently introduce some well known land use models that are based on economic principles. We will then focus on the Land Use Scanner and the way economic theory is incorporated in the model. The theoretical background of the model will then be confronted with practice when we compare the land prices of the Land Use Scanner with an explanatory model on land prices.

2. Economic theories on land prices

Land has special characteristics compared to other economic goods: the supply of land is fixed (with the exception of land reclamation), every parcel of land has a fixed location, which is a unique property, and the use of a parcel of land affects the use and value of surrounding parcels. This last property, which is called an externality of land use, gives rise to government intervention. The special characteristics, the externalities, and intervention make an analysis of the land market rather complicated.

The attention for land in economic theories has changed over time. The early and well-known theories of Ricardo and, in a more spatial context, Von Thünen have laid the foundation of land price and land use theories and are to a certain extent still valid and used in current research. Ricardian land models explain the existence of land rents from differences in fertility, or more general, differences in land quality. Land of a higher quality generates surpluses over land with a lower quality. These surpluses are paid as rent to the landlord due to competition at the land market and at the market for agricultural products. Von Thünen's model is concerned with location and transportation costs, which as well as fertility, are characteristics of a parcel. Though von Thünen merely analysed land use patterns, an important result of his model was the explanation of land prices. Ricardo's and Von Thünen's theories can be extended and improved in may ways (see for example Randall and Castle, 1985).

The bid rent theory is based on microeconomic theory and was mainly developed in the context of urban land uses and urban land values (see for example Alonso, 1964 or Mills and Hamilton, 1994). The bid rent function in the theory explains the relation between urban land uses and urban land values. In a very simplified view, households and companies make a trade off between the land price, transportation costs and the amount of land they use. This results in a convex land price curve with the highest land prices near the city centre. The derivation of agricultural or rural land values in the bid rent theory owes more to Von Thünen's theory (see Isard, 1956) than the work of Alonso. The crop that produces the highest revenue at a certain location will be able to make the highest bid and thus will be cultivated on that parcel. The land is sold to households or firms if their bid is higher than the bid of agriculture; the situation which defines the limits of the city.

The bid rent theory does not directly lead to an operational model for land use and land prices. It relies strongly on an analysis of the market, market prices and bids actors. In reality however the land market is not transparent and market information is often hard to get. Moreover, other values than the market price for land can exist, like the social land value or non-revealed values as a result of zoning restrictions. Other methods, like the hedonic pricing method which values the different amenities of a parcel of land for an actor, can be used to actually determine land prices.

The theories above constitute basically the theoretical economic framework related to the land market in most land use models. The theoretical framework has been extended in many ways to deal with the complexities of the land market (see for example Anas, 1982). Besides the theoretical framework, many empirical studies in the field of land markets and land use contributed considerably to the development of (operational) land use models.

3. Economics-based land use models

Most land use models that have incorporated economic theory in their framework have their roots in the family of spatial interaction models. Spatial interaction models are essentially based on Newtons gravity theory. Geographers as Ravenstein, Young and Reilly described migration in analogy with this theory in the last part of the 19th century and the early 20th century. They assumed that the interaction between two entities depends on their respective size and mutual distance. Lowry further expanded this concept in 1964 when he linked two partial gravity models (for residential location and service location) into a general urban model (Grothe, 1998). Wilson (1967, 1970) revised the gravity model by applying entropy maximising principles from yet another theory of physics. The entropy maximising procedure seeks to reveal the most probable state of interaction of the urban system that corresponds to the largest number of possible microstates (Batten and Boyce, 1986).

People like Huff (1964) attempted to derive the gravity model on the basis of economic principles of utility maximisation. Employing the micro-economic theory of consumer behaviour, an optimal allocation of origins (consumers) to destinations (shops) is obtained by postulating a utility function which reflects the relative preferences of people at the origin zones for the attributes of the destination zones (Briassoulis, 1999). This approach is based on a description of individual choice behaviour and subsequent aggregation e.g. to the level of a market segment. The same utility maximisation framework was used by Alonso (1964) to describe the urban land market. His treatment of the land market inspired many (urban) land use models (e.g. Mills, 1972; Fujita, 1989) that, applied to monocentric cities, provide the well known concentric land use patterns.

The above-mentioned models that apply utility maximisation all have a micro-economic focus on the behaviour of individuals. A more general, macro-economic approach is used in the equilibrium models that consider the balancing of supply and demand. Models that concentrate on more than one market (e.g. housing and agriculture) and more than one region are generally referred to as spatial general equilibrium models. The development of an operational, computable version of these theoretic models is difficult, since a lot of detailed information is needed on demand and supply side of the various considered markets. It is even more difficult to make these models spatially explicit. The Land Use Scanner which is presented in the next section uses the equilibrium principle. It does however not contain a complete description of the various sectors, but rather than that, it integrates the outcomes of other sectoral models and allocates them in a highly disaggregated way.

4. Land Use Scanner

The Land Use scanner is a GIS based model that simulates future land use and which offers an integrated view on all types of land use. It deals with urban, natural and agricultural functions, normally distinguishing 15 different land use categories. The model is grid based, covering the Netherlands in almost 200,000 cells of 500 by 500 meter. Each cell describes the relative proportion of all present land use types, i.e. a cell can contain more than one type of land use. It thus presents a highly disaggregated description of the whole country. Regional projections of land use change are used as input for the model. These projections are derived from the sectoral models of specialised institutes. The various land use claims are allocated to individual grid cells based on their suitability. Suitability maps are generated for all different land use types based on location characteristics of the grid cells in terms of physical properties, operative policies and expected relations with nearby land use functions. Unlike many other land use models the objective of the Land Use Scanner is not to forecast the dimension of land use change but rather to integrate and allocate future land use claims from different sectoral models. The outcomes of the model should not be interpreted as a fixed prediction for a particular location but rather as probable spatial patterns.

The Land Use Scanner employs the equilibrium principle to balance the demand for various land use functions with the supply of suitable land. The crucial variable for the allocation model is the suitability s_{cj} for land use of type j in grid cell c. This suitability can be interpreted to represent the net benefits (benefits minus costs) of land use type j in cell c. The higher the suitability for land use type j, the higher the probability that the cell will be used for this type. In the simplest version of the model a logit type approach is used to determine this probability. The model is constrained by two conditions: the overall demand for the land use functions which is given in the initial claims and the total amount of land which is available for each function. By imposing these conditions a doubly constrained logit model arises that can be formulated as:

$$M_{cj} = a_j \cdot b_c \cdot \exp(\beta \cdot s_{cj})$$

In which:

M_{cj} is the expected amount of land in cell c that will be used for land use type j .

a_j is the demand balancing factor that ensures that the total amount of allocated land for land use type j equals the sectoral claim.

b_c is the supply balancing factor that makes sure the total amount of allocated land in cell c does not exceed the amount of land that is available for that particular cell.

β is a parameter that allows for the tuning of the model. A high value for β makes the suitability more important in the allocation and will lead to a more mixed use land pattern, strongly following the suitability pattern. A low value will produce a more homogenous land use pattern.

s_{cj} is the suitability of cell c for land use type j, based on its physical properties, operative policies and neighbourhood relations.

See Hilferink and Rietveld (1999) for a detailed description of the mathematical formulation.

The conflict of competing claims is reconstructed in the model as a bidding process. The land use type with the highest claim in relation to the amount of land that is initially allocated for it will offer the highest bid on the available land. These bids can be traced in the mathematical formulation as the demand balancing factor a_j. The iterative simulation process yields as a side product an indication of land scarcity. The land scarcity for each cell depends on the demand balancing factor, the suitability and the available space in the cell. This land scarcity can be interpreted as a land price and is mathematically defined as:

$$p_c = \frac{1}{\beta} \cdot \log\left[\frac{\sum_j a_j \cdot \exp\left(\beta \cdot s_{cj}\right)}{L_c}\right]$$

In which:

Pc is the land price indication for cell c

L_c denotes the total amount of available land in cell c

5. Comparing the Land Use Scanner land prices

In order to compare the Land Use Scanner land price indication with actual land prices we made use of a land price model that is being developed for the Dutch province of Noord-Brabant (Buurman, 2001). This model focuses on explaining spatial patterns in rural land prices. Therefore a large set of data has been collected and analysed in a GIS. The data comprise 20,000 parcels that changed owner in the period January 1998 till July 2001. Apart from transaction characteristics such as price, the data set also includes geographical themes like: infrastructure, land use, soil type and land use plans.

With these data a regression model has been constructed that explains transaction prices. The regression model can also be used to predict land prices and to create a full coverage map based on a limited number of observations. Starting from a given land use situation and a set of statistical relations a theoretical land price can be calculated for every grid cell. With the Land Use Scanner the land use situation for the year 2000 was simulated based on: the present land situation (1995), additional land use claims from various institutions and current land use policies. The simulated land use was taken as input for the land price model. Figure 1 shows the resulting land prices from both the land price model and the land use scanner.

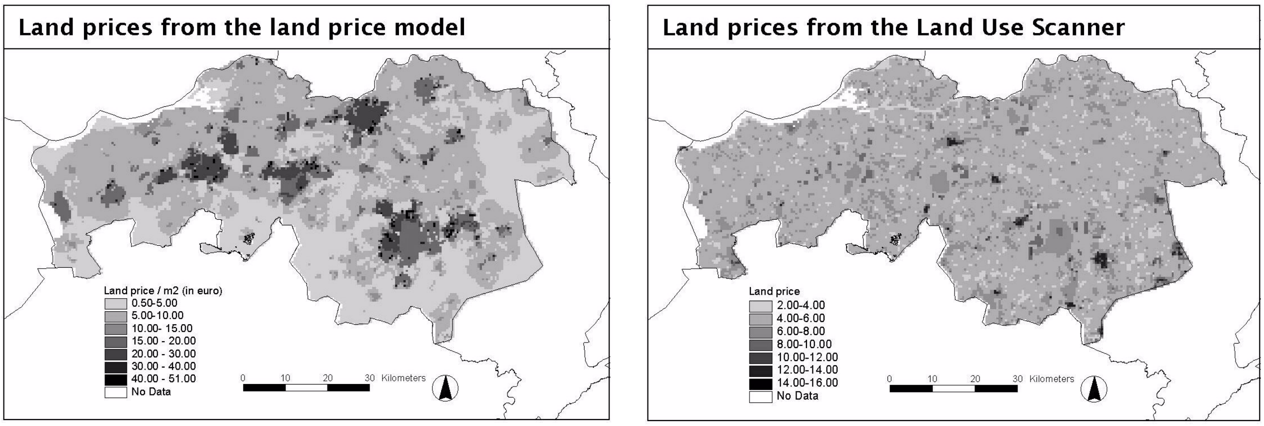

Figure 1 Land prices from the rural land price model and the Land Use Scanner. Note that the latter lack a proper unit and solely represent land scarcity in the model.

When comparing the outcomes of the two models one should bare in mind that they were developed for different purposes. The land price model is developed for explaining land prices in rural areas, so the outcomes in urban areas should be viewed with suspicion. The main objective of the Land Use Scanner is to provide probable land use simulations, its land prices reflect the scarcity of land and are not scaled to monetary units. We should therefor focus on the spatial patterns instead of the actual values. The land price model offers a more pronounced map, showing the full range of low and high values. The low values are mostly found at the southern national border and the eastern provincial border. High values characterise the urban areas and especially the urban fringes. The Land Use Scanner land price map is dominated by relatively low values, whereas the extremes seem to be less present. Intermediate values can be observed in the central urban areas, the highest values seem to prevail in the natural areas.

The fact that the Land Use Scanner produces a less outspoken land price map may be related to the short period of simulation and absence of strongly conflicting land use claims. The high land prices in the natural areas reflect the strong wish of the government to increase natural values in the Netherlands. This wish is supported by zoning laws that are included in the Land Use Scanner. These measures are however not reflected in the actual land prices. Further research on the Land Use Scanner will focus on an economically more realistic inclusion of the planning policies for natural areas and price formation over a longer simulation period.

6. Conclusion

Preliminary results of the present study indicate that the economic foundation of the operational Land Use Scanner model does not guarantee realistic land prices. Apart from obvious problems in simulating land prices such as government intervention and a non-transparent market, the link between theories of land use and land price could prove to be difficult to establish from both an operational and theoretical point of view.

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